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KEYWORDS: priderite, system $K_2MgTi_7O_{16}$–$BaMgTi_7O_{16}$, wadeite.

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A contact-metamorphic occurrence of the assemblage nepheline–scapolite–diopside in a metabasic flow breccia from Bergslagen, Sweden

THE 1.9–1.8 Ga-old volcanic-sedimentary sequence in the Saxå sedimentary rift basin, 8 km SW of Hällefors, Western Bergslagen, Sweden (fig. 1) comprises (from old to young) acid metapyroclastics and marbles of the Middle Leptite Group, and metatuffites with metabasic sills, dykes and flows, overlain by phyllites, all of the Upper Leptite-hälleflinta and Slate Group (Oen *et al.*, 1982). Rifting, block faulting and compressive deformation resulted in the present symmetrical configuration of the area with generally westerly dipping strata. Intrusion of the 1694 ± 191 Ma Filipstad granite (Rb–Sr whole rock; Oen, 1983) truncated the folded Saxå rift basin to the south (fig. 1).

Nepheline associated with scapolite, diopside, andesine, biotite, and calcite has been observed in a metabasic flow breccia of the Upper Leptite-hälleflinta and Slate Group, at a distance of 150 m from the Filipstad granite. Metabasic flows and flow breccias from the same stratigraphic level, but further away from the granite, contain hornblende-andesine-biotite-calcite-quartz-sphene. In this paper evidence is presented supporting a contact metamorphic origin for the nepheline-scapolite-diopside assemblage, caused by the intrusion of the Filipstad granite.

The metatuffites belonging to the Upper Leptite-hälleflinta and Slate Group contain the assemblages hypersthene-andalusite-biotite-quartz and corundum-microcline-sericite-scapolite-andalusite-biotite-sphene adjacent to the granite instead of the assemblages hornblende-biotite-quartz-plagioclase and microcline-diopside-scapolite-biotite-sphene further away from the granite. The temperature, estimated from these assemblages, lies roughly between 500 and 700 °C (Hellingwerf, 1981), based on data of Evans (1965), Turner (1968), Haas (1972), and Sobolev (1972).

The temperature of the country rock adjacent to the solidifying Filipstad granite has been calculated to be roughly 500 °C (Hellingwerf, unpubl. data), using the equations of Jaeger (1957, 1959).

The nepheline-bearing metabasic flow breccia consists of small (< 2 cm), angular metabasic fragments, cemented by calcite. The fragments show relict vesicular textures with calcite-filled amygdules (fig. 2). Crystallization of (calc-) silicates has obliterated most of the original pilotaxitic, glomeroporphyritic, and intersertal textures (Hellingwerf, 1981). The present texture is characterized by poikiloblastic nepheline and scapolite, and granoblastic diopside and calcite. Minor but conspicuous quantities of pyrrhotite are present in the diopside-rich aggregates. The fragments also contain minor hornblende, poikiloblastic brown biotite, anhedral andesine, and accessory ilmenite rimmed by sphene, apatite, cubanite, chalcopyrite and hematite (Table I).

Electron microprobe analyses of nepheline, scapolite, and andesine were made on a Cambridge

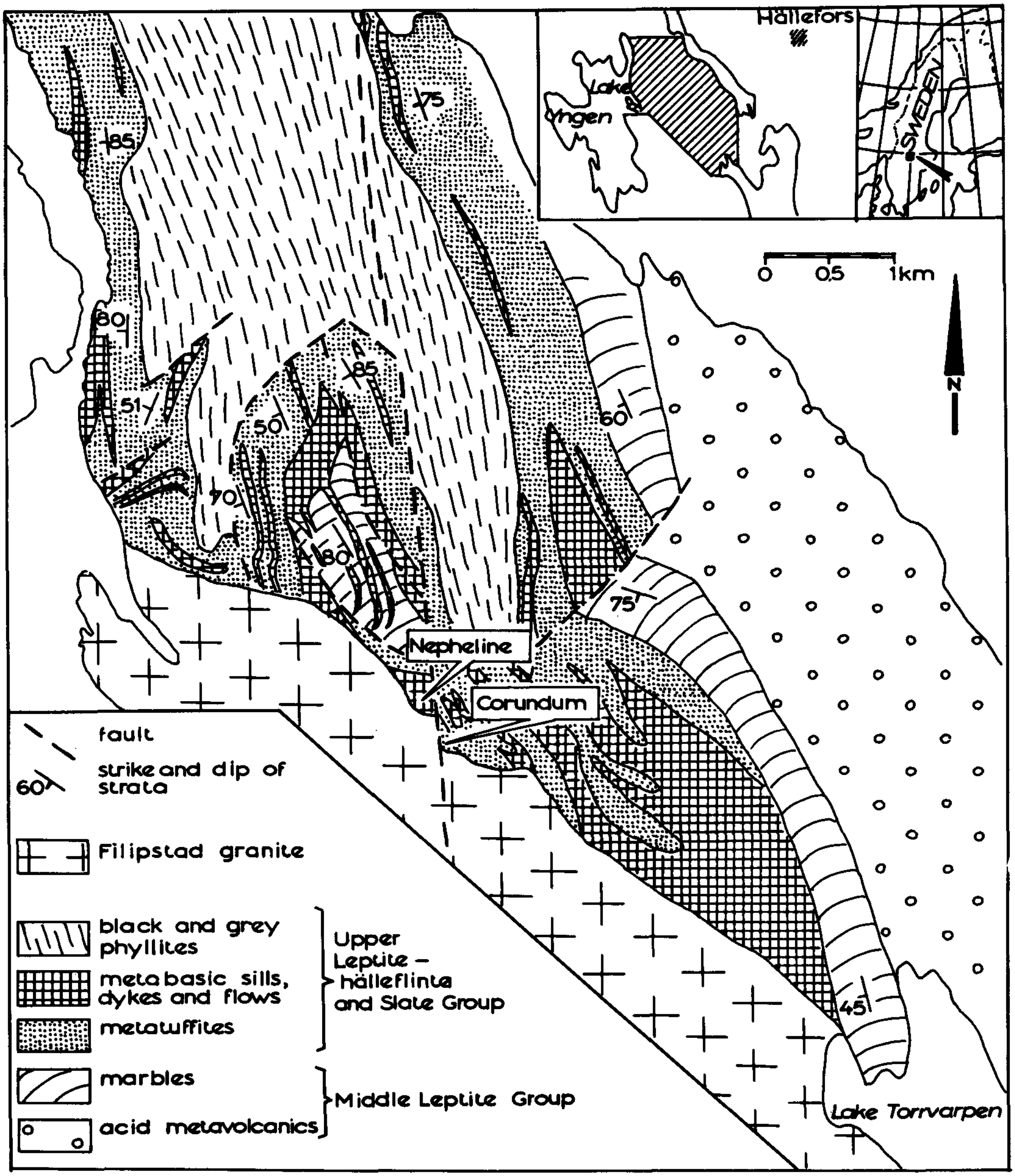


FIG. 1. Geological sketch-map of the southern part of the Saxå sedimentary rift basin. The 1694 ± 191 Ma Filipstad granite truncates the folded volcanic–sedimentary sequence to the south (modified from Hellingwerf, 1984).

Geoscan equipped with a LINK energy dispersive system (Table II).

Nepheline occurs only in the metabasic fragments as anhedral grains and poikiloblasts up to 2 mm, locally in and around andesine (fig. 3), and locally intergrown with scapolite poikiloblasts (fig. 4) and granoblastic diopside. Occasionally nepheline contains elongate inclusions of calcite parallel to the cleavage directions. This observation, together with the presence of nepheline in and around andesine (fig. 3), suggests replacement of andesine by nepheline. Though uniaxial, occasional biaxial negative interference figures with a very small optic axial angle ($\leqslant 5°$) were observed. Also a vague

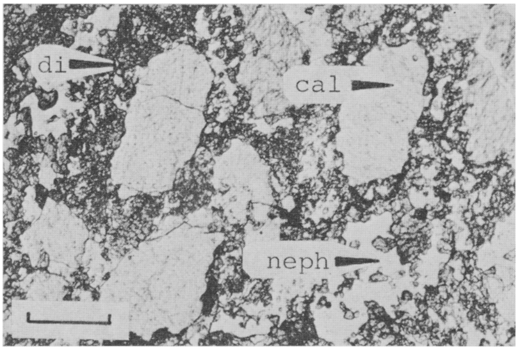


FIG. 2. Microphotograph showing vesicular texture in metabasic flow. The amygdules are filled with calcite (cal); the matrix contains diopside (di), nepheline (neph), and scapolite (scap) (one nicol, bar = 0.5 mm).

TABLE I. Mineral composition of the nepheline-bearing metabasic flow breccia (The contents are estimated from thin sections).

Low-pressure amphibolite facies assemblage	Pyroxene hornfels facies assemblage
andesine (5-10 vol%)	nepheline (10-20 vol%)
hornblende (1-2 ,,)	diopside (20-35 ,,)
scapolite	scapolite (8-25 ,,)
calcite	calcite (25-40 ,,)
pyrrhotite	pyrrhotite (1-2 ,,)
quartz	-
biotite	biotite (access.)
microcline	microcline (,,)
ilmenite	-
sphene	sphene (,,)
apatite	apatite (,,)
chalcopyrite	chalcopyrite (,,)
cubanite	cubanite (,,)
	hematite (,,)

polysynthetic twinning can sometimes be seen (fig. 5). These phenomena are probably due to lattice deformations. Part of the nepheline shows weak kaolinitization along the cleavage.

Electron microprobe analyses of nepheline show K_2O contents between 3.4 and 4.0 wt. %. K_2O appears inhomogeneously distributed within the nepheline grains. CaO ranges between 2.3 and 3.0 wt. %, and its content is generally lower in the core than in the rim, especially where in contact with andesine or calcite (Table II).

Scapolite occurs in the metabasic fragments as poikiloblasts up to 4 mm, replacing andesine. These large grains ocassionally show undulose extinction. Small grains of scapolite (< 0·5 mm) also occur along the rims of the amygdules, replacing calcite. Electron microprobe analyses indicate a high meionite content (Table II).

Diopside replaces coarse grained calcite, especially along the rims of the amygdules. Diopside also replaces aggregates of recrystallized amphiboles. Electron microprobe analyses of diopside indicate a hedenbergite component of approximately 30 wt. % (Hellingwerf, unpubl. data).

At least two mineral assemblages occur in the metabasic flow breccia adjacent to the Filipstad granite, presented in Table I. The older low-pressure amphibolite facies metamorphic assemblage hornblende-andesine-biotite-calcite-quartz-sphene occurs throughout the Saxå area in metabasic flow breccias, at distances more than 150 m from the Filipstad granite. The younger low-pressure high-temperature assemblage nepheline-scapolite-diopside occurs only in the metabasic flow breccia adjacent to the granite. Textural relationships of this later replacing assemblage (poikiloblastic intergrowths of nepheline and scapolite, the replacement of calcite by scapolite and diopside, and of amphibole by diopside) clearly show that nepheline, scapolite, and diopside crystallized during the same younger phase of metamorphism.

A contact metamorphic origin for the assemblage nepheline-scapolite-diopside is supported by the following arguments:

(1) Nepheline is contained only in the first 150 m of an almost continuously exposed 300 m long section of a metabasic flow breccia running perpendicular to, and away from, the contact of the Filipstad granite.

(2) High-temperature metamorphic assemblages in both metabasites and metatuffites define a contact zone adjacent and parallel to the granite contact.

(3) The temperatures required to form corundum, hypersthene, and diopside in the contact zone are compatible with the temperature of the country rock adjacent to a solidifying granite.

(4) In the amygdules calcite is replaced both by diopside and scapolite; in the matrix amphibole is replaced by diopside and pyrrhotite; andesine seems to be replaced by scapolite and by nepheline (fig. 3).

(5) The inhomogeneous distributions of K_2O and CaO in nepheline, and an apparent increase in CaO towards andesine or calcite, favour a metamorphic origin.

(6) The absence of carbonatites and nepheline syenites in this district excludes an igneous or an igneous-metasomatic origin for the nepheline-scapolite-diopside assemblage.

Duffin (1964) reported the crystallization of

Table II. Electron microprobe analyses of nepheline, scapolite and andesine

	1	2	3	4	5	6	7 (n=11) mean	7 (n=11) std. dev.	8	9	10	11 (n=3) mean	11 (n=3) std. dev.
SiO_2	43.52	43.23	43.54	42.84	43.26	42.16	43.11	.46	42.42	41.84	59.14	59.36	.49
Al_2O_3	35.31	35.19	35.56	34.09	34.15	34.28	34.67	.49	28.11	28.15	25.03	24.96	.23
CaO	2.72	2.85	3.02	2.48	2.30	2.68	2.61	.26	20.47	20.22	7.48	7.24	.46
Na_2O	14.63	14.76	14.70	14.96	15.36	14.65	14.82	.39	2.94	2.32	8.02	7.93	.34
K_2O	3.63	3.64	4.03	3.57	3.50	3.40	3.75	.32	-	-	-	-	
S									-	-			
Cl									.11	.16			
Total	99.81	99.67	100.85	97.94	98.57	97.17	98.96		94.05	92.69	99.67	99.49	
	number of ions on the basis of 4 oxygens								25 oxygens		8 oxygens		
Si	1.031	1.027	1.024	1.036	1.039	1.027	1.032	.005	6.656	6.647	2.653	2.663	.015
Al	.986	.986	.986	.972	.967	.985	.979	.007	5.200	5.272	1.324	1.320	.008
Ca	.069	.073	.076	.064	.059	.070	.067	.006	3.441	3.442	.360	.348	.023
Na	.672	.680	.671	.701	.715	.692	.688	.020	.894	.715	.698	.690	.032
K	.110	.110	.121	.110	.107	.106	.114	.010	-	-	-	-	

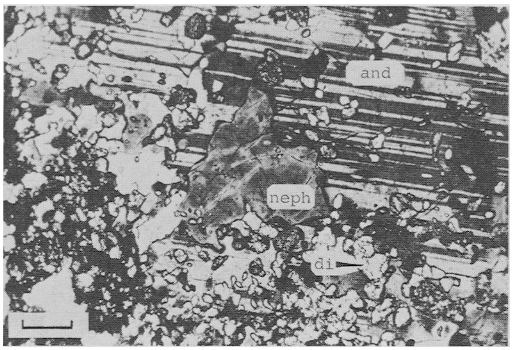
nos. 1, 2, 3: nepheline (1=core, 3=rim) in contact with plagioclase (no. 10)

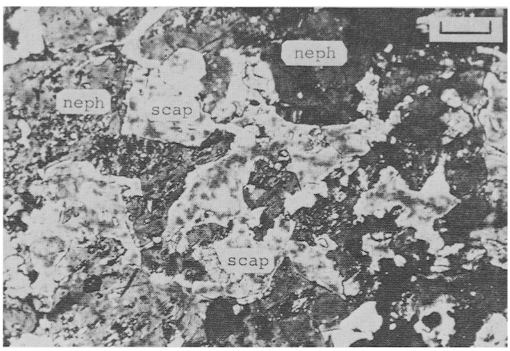
no. 4: nepheline in contact with scapolite (n s. 8, 9)

nos. 5, 6: nepheline (5=core, 6=rim) in contact with calcite

no. 7: mean and standard deviation of 11 nepheline analyses

no. 11: mean and standard deviation of 3 andesine analyses





FIGS. 3 and 4. FIG. 3 (*left*). Microphotograph showing anhedral nepheline (neph) and granoblastic diopside (di) replacing andesine (and). FIG. 4 (*right*). Microphotograph showing poikiloblastic intergrowth of nepheline (neph) with scapolite (scap) (both under crossed nicols, bar = 0.1 mm).

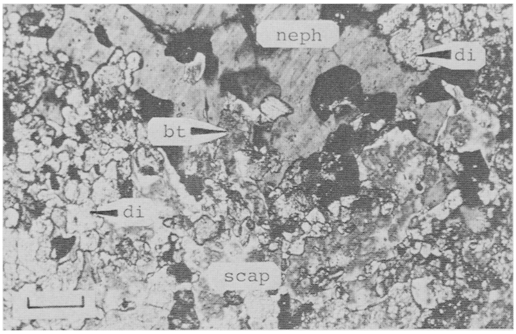


FIG. 5. Microphotograph showing nepheline poikiloblast (neph), scapolite (scap), granoblastic diopside (di), and brown biotite (bt). Note the polysynthetic twin lamellae in the nepheline (crossed nicols, bar = 0.1 mm).

nepheline and sodalite in heating experiments of plagioclase powder with rock-salt. Rao Murthy (1974) described the metasomatic replacement of plagioclase by nepheline and perthite in a Si-deficient environment. Williams-Jones (1981) observed nepheline in the inner contact aureole of a gabbroic stock and presented the reaction

$$2 \text{ calcite} + \text{albite} \rightarrow \text{nepheline} + 2 \text{ wollastonite} + 2\ CO_2.$$

The following equation for the formation of the assemblage nepheline–scapolite–diopside described in this paper from the assemblage andesine–hornblende–calcite in the metabasic flow breccia is suggested on the basis of microscopic observations and electron microprobe analyses:

$$2[(NaAlSi_3O_8)_2 \cdot CaAl_2Si_2O_8](\text{andesine}) + 5CaCO_3(\text{calcite}) + 2Ca_2(Mg,Fe)_5AlSi_6Al_2O_{22}(OH)_2(\text{hornblende}) + SO_2 \rightarrow 6NaAlSiO_4(\text{nepheline}) + 4CaAl_2Si_2O_8(\text{meionite}) + 7Ca(Mg,Fe)Si_2O_6(\text{diopside}) + 5CO_2 + 2H_2O + 1.5O_2 + FeS.$$

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